

secured (e.g., glued into place). Midsection **316** fits around the top of base **302** and is rotationally aligned to be square with base **302**. Upper base bearing **318** fits closely inside top section **320**, and is rotationally aligned such that bearing slots **318a** are aligned with top slots **320a**, constituting constraint pin slots **300a**. Top section **320** fits closely around the top of midsection **316** and is rotationally aligned to be square with midsection **316** and base **302**.

[0051] Magnet **304** is preferably a high-strength permanent magnet. Base **302**, flux disk **306** and midsection **316** are preferably made of a ferromagnetic material with good permeability (e.g., steel alloy 12L14). The top and sides of flux disk **306** are preferably painted black before assembly. Top section **320** is preferably made of a non-ferromagnetic material (e.g., 6110-T6 aluminum alloy). Upper base bearing **318** and lower base bearing **314** are preferably made of a low-friction material (e.g., PTFE). Proximity sensor **308** may be implemented using, for example, a reflective proximity sensor containing an LED (not shown) and a phototransistor (also not shown).

[0052] FIG. 4 illustrates an exploded perspective view of a haptel stationary assembly **300** mounted to a support plate **402**. Support plate **402** is made of a rigid material with good heat conductivity, such as aluminum plate. It will be noted that FIG. 4 shows only a portion of support plate **402**. Mounting hardware **404** may consist of two sets of machine screws, nuts and washers, for example. In one embodiment, the machine screws are routed through two diagonally opposite holes in haptel stationary assembly **300** and through support plate **402**, and are fastened securely to the other side using nuts and washers. Position cable **310** is routed through a center hole in support plate **402**. The hole pattern in support plate **402** should match the hole pattern in base **302**.

[0053] FIG. 5A illustrates an exploded perspective view of the parts and assemblies of a haptel such as haptel **500**. FIG. 5B illustrates a perspective view of haptel **500**. Moving assembly **100** fits inside stationary assembly **300**. Moving assembly **100** is preferably aligned such that constraint pin holes **100a** are aligned within constraint pin slots **300a**, making surface **102** of moving assembly **100** square with stationary assembly **300**. Constraint pins **200** are glued into constraint pin holes **100a**, fitting within, but not affixed to, constraint pin slots **200a**. Coil cable **114** and XY cable **118** are routed through the remaining corner holes in stationary assembly **300** and support plate **402**.

Grid description

[0054] FIG. 6A illustrates an exploded perspective view of the parts included in grid assembly **600**. FIG. 6B illustrates a perspective view of grid assembly **600**.

[0055] Unified support plate **602** is shown in FIG. 6A as having nine haptels (e.g., haptel **500**) in a 3x3 grid configuration. Unified support plate **602** replaces support plate **402** for all haptels in the grid. The rectangularly arranged set of nine haptels is referred to as a haptel grid **604**. The bolts, coil cables, position cables, and XY cables of all haptels go through appropriately positioned holes in unified support plate **602**. In addition, there is a hole in the unified support plate beneath each base air hole **302b**. Preferably, grid overlay **606** is affixed to haptel grid **604** at the centers of the haptel surfaces. Grid overlay **606** is a thin, slick, flexible and

stretchable material, such as .010" thick urethane elastomer sheet with **60** Shore A durometer hardness. Hand rest **608** is affixed to support plate **602** with grid feet **610**. Hand rest **608** is preferably made of injection molded plastic, while grid feet **610** are preferably plastic with standard screws centrally embedded therein. The screws projecting from grid feet **610** preferably thread into holes in vertical supports **608a**. The height of vertical supports **608a** ensures that the upper surface of hand rest **608** is flush with the upper surface of haptel grid **604** when assembled.

System description

[0056] FIG. 9 illustrates a block diagram depicting the functional elements of an embodiment of the present invention. An input/output (I/O) device **900** includes haptels **500(1)-(N)**, position circuits **700(1)-(N)**, actuator circuits **800(1)-(N)**, XY interfaces **912(1)-(N)** and a control system **902**. Control system **902** includes an analog input card **906**, two serial cards **910**, a digital output card **908**, and a control processor **904**. Functional elements of haptels **500(1)-(N)** are shown as a group containing magnet wires **108(1)-(N)**, proximity sensors **308(1)-(N)** and XY sensors **116(1)-(N)**.

[0057] It will be noted that the variable identifier "N" is used in several instances in FIG. 9 to more simply designate the final element (e.g., haptel **500(N)**, XY sensor **116(N)**, and so on) of a series of related or similar elements (e.g., haptels **500(1)-(N)**, XY sensor **116(1)-(N)**, and so on). The repeated use of such variable identifiers is not meant to imply a correlation between the sizes of such series of elements, although such series may be equal in extent. The use of such variable identifiers does not require that each series of elements have the same number of elements as another series delimited by the same variable identifier. Rather, in each instance of use, the variable identified by "N" may hold the same or a different value than other instances of the same variable identifier. For example, haptel **500(N)** may be the ninth in a series of haptels, whereas XY sensor **116(N)** may be the forty-eighth XY sensor in a series of XY sensors. In the preferred embodiment, N equals nine for all series.

[0058] Each one of haptel proximity sensors **308(1)-(N)** is coupled via a corresponding one of position cables **310(1)-(N)** to a corresponding one of position circuits **700(1)-(N)** as described in FIG. 7. The output of each one of position circuits **700(1)-(N)** is coupled to an input of analog input card **906**, which is installed in control system **902** and communicates with control processor **904** via a communications channel such as PCI bus **922**. Analog input card **906** is preferably a high-speed data acquisition card with a number of inputs corresponding to the number of haptels in haptel grid **604** and may employ devices such as those available from National Instruments of Austin, Tex. under the trade designation PCI-6023E. Magnet wires **108(1)-(N)** couple their respective haptel via one of coil cables **114** to the outputs of a respective one of actuator circuits **800(1)-(N)**, described in FIG. 8. The inputs of each of actuator circuits **800(1)-(N)** are coupled to the outputs of digital output card **908** which is shared by actuator circuits **800(1)-(N)**. Digital output card **908** is installed in control system **902** and communicates with control processor **904** via a communications channel such as a device PCI bus **922**. Digital output card **908** preferably provides at least 14 bits